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(54) Jitter measurement in signal transmission systems

(57) A test signal from a generator 10, having a frequency within the range of a signal transmission system, is modulated at 11 by a low frequency signal, from a generator 12, outside the range of the transmission system and is applied to the system 13. The instantaneous peak-to-peak phase jitter of the transmitted signal is detected, 14, and sampled at low and high amplitudes of the test signal to provide respective signals 16, 17 to gates 18, 19. The selector 15 also provides selected low and high level amplitude signals T_1, T_2 and the ratio T_1/T_2 is produced at 22. A unit 23 processes the signals T_1 and T_1/T_2 and a unit 24 processes the signal T_1/T_2.

Signal processing circuit, 25–28, output a signal representing true phase jitter, K, and a signal representing noise and interference components, N + I, of the detected jitter.

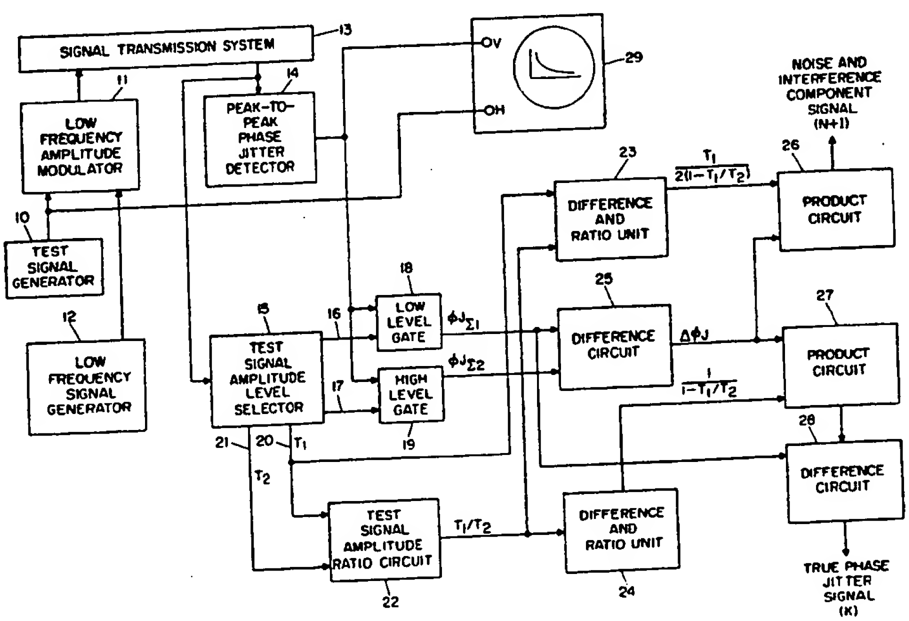

FIG. 3

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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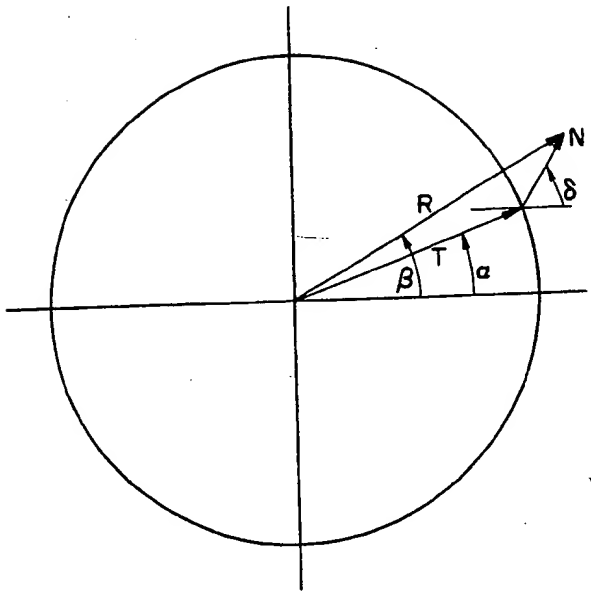

FIG. 1

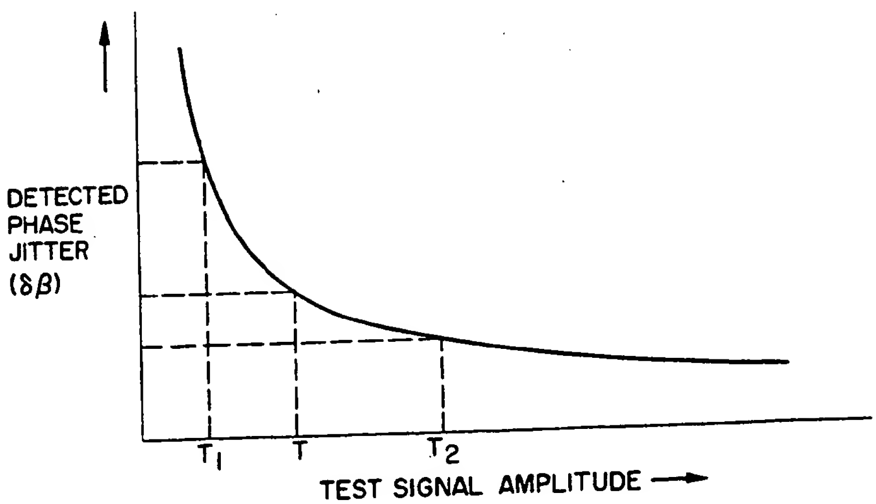

FIG. 2

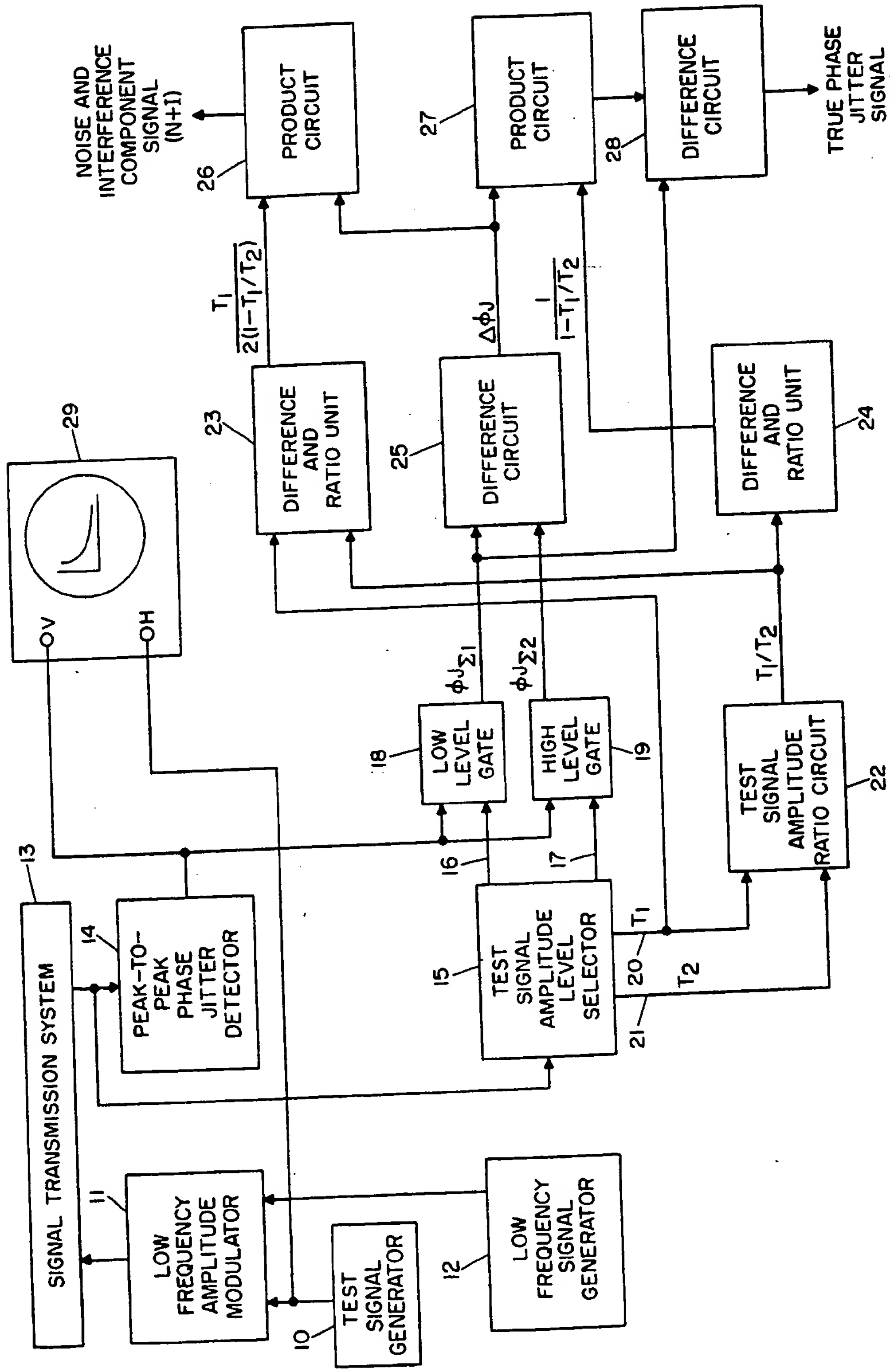
SIGNAL TRANSMISSION SYSTEM
13
LOW FREQUENCY AMPLITUDE MODULATOR
11
TEST SIGNAL GENERATOR
10
LOW FREQUENCY SIGNAL GENERATOR
12
PEAK-TO-PEAK PHASE JITTER DETECTOR
14
TEST SIGNAL AMPLITUDE LEVEL SELECTOR
15
16
17
20
21
T_1
T_2
LOW LEVEL GATE
18
HIGH LEVEL GATE
19
TEST SIGNAL AMPLITUDE RATIO CIRCUIT
22
$\phi J_{\Sigma 1}$
$\phi J_{\Sigma 2}$
T_1/T_2
V
H
29
DIFFERENCE AND RATIO UNIT
23
DIFFERENCE CIRCUIT
25
DIFFERENCE AND RATIO UNIT
24
$\frac{T_1}{2(1-T_1/T_2)}$
$\Delta\phi J$
$\frac{1}{1-T_1/T_2}$
PRODUCT CIRCUIT
26
PRODUCT CIRCUIT
27
DIFFERENCE CIRCUIT
28
NOISE AND INTERFERENCE COMPONENT SIGNAL (N+I)
TRUE PHASE JITTER SIGNAL (K)

FIG. 3

SPECIFICATION

Jitter measurement in signal transmission systems

This invention relates to the measurement of performance characteristics of signal transmission systems and, more particularly, to the measurement of the true jitter characteristics of a signal transmission system.

Equipment designed to transmit signals over band-pass channels such as telephone systems usually uses phase and/or amplitude modulation of an in-band carrier in accordance with the information being transmitted. Certain transmission system components or transmission conditions may produce undesired variations in the phase, as well as the amplitude of the signals received from the transmission system, which result in unacceptable performance of the system.

In order to detect such unacceptable performance conditions and isolate their causes, transmission systems are frequently evaluated by applying a test signal of selected frequency and analysing the resulting signal received from the transmission system as described, for example in U.S. patents nos: 3,711,773, and 3,916,307. One of the significant system characteristics determined in such analysis is called jitter, which is a measure of the variation in the phase or amplitude of the received signal from the transmitted signal.

Conventional jitter measurement systems, however, are responsive not only to the actual or true phase or amplitude jitter produced by the transmission system but also to the effects of noise and other interference introduced into the signal by the transmission system. Accordingly, the jitter indications provided by conventional phase of amplitude jitter measurement systems are not accurately representative of the true jitter condition caused by the system but represent instead the combined effects of the true jitter and that due to noise and interference contributions to the jitter measurement.

Accordingly, it is an object of the present invention to provide a jitter measurement technique which overcomes the above-mentioned disadvantages and which preferably provides separate indications of the true phase jitter contribution and that due to the interference and noise contribution of an indicated phase jitter measurement.

This is accomplished in accordance with the invention by generating a sinusoidal test signal of selected frequency within the normal frequency range of the transmission system, generating an indicated jitter signal corresponding to an instantaneous jitter characterstic in the test signal transmitted by the transmission system, sampling the indicated jitter signal at high and low amplitude of the test signal, and using the sampled jitter signals and signals corresponding to the high and low test signal amplitudes to generate a signal representing a true jitter component resulting from transmission of the test signal through the transmission system. In a particular example of this method, the indicated phase jitter characteristic of the transmitted test signal is analysed to determine the true phase jitter and the indicated phase jitter signal may also be analysed to determine the noise and interference components of that signal which are introduced by the transmission system.

Apparatus for determining jitter components of a test signal transmitted by a transmission system in accordance with the present invention comprises test signal generating means for generating a test signal having a frequency within the range of the transmission system which is amplitude modulated at a frequency below the frequency range of the transmission system, jitter detector means providing a signal representing an instantaneous jitter characteristic of the test signal transmitted by the transmission system, sampling means for sampling the indicated jitter signal at two different amplitudes of the test signal, and means responsive to the sampled indicated jitter signals and to signals representing the two different amplitudes of the test signal for providing an output signal representing a true jitter component in the transmitted test signal. If desired, the apparatus may include an oscilloscope presenting a graphical representation of the instantaneous indicated jitter signal with respect to test amplitude.

The test signal frequency used in determining true phase jitter in accordance with the invention may be any of the conventional transmission system test signals, such as at 400, 800, 1000, 1700 or 2800 Hz, and the frequency of the low frequency amplitude modulation of the test signal may be on the order of a few Hz, preferably about 1 to 5 Hz, while the per centage modulation of the test signal is preferably between about ten per cent and about fifty per cent.

The invention will now be described in more detail with reference to the accompanying drawings in which:–

Figure 1 is a vector diagram illustrating the contributions of different components to the indicated phase of a detected signal resulting from a test signal and an added noise signal;

Figure 2 is a graphical representation illustrating the variation of indicated phase jitter with test signal amplitude; and

Figure 3 is a schematic block diagram showing a representative phase jitter measurement system in accordance with the invention.

In the diagrammatic representation shown in Fig. 1, the effects of additive components of noise or interference in producing phase modulation of a test signal are illustrated. In that illustration, the test signal, represented by the vector T, has an amplitude corresponding to the length of the vector and a phase represented by the angle α. An additive component, such as a noise signal represented by the vector N, having a phase represented by the angle γ, when combined with the test signal T, produces a resultant signal represented by a vector R. In the illustrated example the resultant signal R has a larger amplitude and a phase angle represented by the angle β.

To determine the characteristics of a composite signal R, in terms of the amplitude and phase angle of the test signal and noise components, the following expressions may be used:

$$R(\text{real}) = T \cos\alpha + N \cos\gamma \qquad (1)$$

$$R(\text{imag}) = T \sin\alpha + N \sin\gamma \qquad (2)$$

From these expressions, the arguments, or phase angle of the resultant signal R can be determined by the following relation:

$$\beta = \tan^{-1}\left[\frac{T \sin\alpha + N \sin\gamma}{T \cos\alpha + N \cos\gamma}\right] \qquad (3)$$

Using the vector T as a reference, the variation in phase angle $\delta\beta$, resulting from the addition of the noise signal N to the test signal T is represented in the following manner:

$$\delta\beta = \tan^{-1}\left[\frac{N \sin(\gamma-\alpha)}{T + N \cos(\gamma-\alpha)}\right] = \tan^{-1}\left[\frac{\sin(\gamma-\alpha)}{\left(\frac{T}{N}\right) + \cos(\gamma-\alpha)}\right] \qquad (4)$$

For expression (4), it is apparent that for any given noise signal, the detected phase shift $\delta\beta$, of the resultant signal will increase at a substantially increasing rate as the amplitude of the test signal is reduced, and will decrease at a decreasing rate as the amplitude of the test signal increases. This is illustrated in Fig. 2, in which a test signal T_1, having half the amplitude of the test signal T, causes the resultant signal to have a phase shift, corresponding to detected phase jitter, which is approximately twice that of the original resultant signal, while a test signal T_2, having twice the amplitude of the test signal T, produces a resultant signal phase shift which is approximately three quarters that of the original resultant signal.

In the measurement of phase jitter, the contribution of the true jitter, corresponding to variations in α in the diagram of Fig. 1, is constant with the amplitude of the test signal T. On the other hand, the contributions of additive noise signals N and other interference signals I, each corresponding to a vector similar to the vector N of Fig. 1, to the indicated phase jitter, $\delta\beta$, are dependent upon the amplitude of the test signal T and vary with that amplitude in the manner illustrated in Fig. 2. Thus the phase jitter component resulting from noise can be represented by the expression:

$$\phi J_N = 2 \sin^{-1}(N/T) \qquad (5)$$

and the component corresponding to other additive interference signals I can be represented by the expression:

$$\phi J_I = 2 \sin^{-1}(I/T), \qquad (6)$$

whereas the true phase jitter does not vary with test signal amplitude and can be represented by the expression:

$$\phi J_T = K \qquad (7)$$

Since the peak-to-peak indicated phase jitter ϕJ_Σ is the resultant of the components ϕJ_N, ϕJ_I, and ϕJ_T, it can be represented by the summation of those components in the following expression:

$$\phi J_{\Sigma} = K + 2\sin^{-1}\left(\frac{N}{T}\right) + 2\sin^{-1}\left(\frac{I}{T}\right) \quad (8)$$

Since the angles involved are small, this can be approximated as follows:

$$\phi J_{\Sigma} = K + 2\left(\frac{I+N}{T}\right) \quad (9)$$

Accordingly, for two different amplitude levels of the test signal T, represented by T_1 and T_2, the indicated phase jitter signals are represented by

$$\phi J_{\Sigma_1} = K + 2\,\frac{I+N}{T_1} \qquad (10)$$

and

$$\phi J_{\Sigma_2} = K + 2\,\frac{I+N}{T_2} \qquad (11)$$

Subtracting the indicated phase jitter values at the two amplitude levels T_1 and T_2 provides a difference value $\Delta\phi J$, in accordance with the following expression:

$$\phi J_{\Sigma_1} - \phi J_{\Sigma_2} = \Delta\phi J = 2(I+N)\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = 2(I+N)\left(\frac{T_2 - T_1}{T_1 T_2}\right) \qquad (12)$$

This allows us to calculate the true jitter value K and the interference plus noise jitter contributions I + N in the following manner:

$$K = \phi J_{\Sigma_1} - 2\,\frac{I+N}{T_1} = \phi J_{\Sigma_1} - \frac{\Delta\phi J \cdot T_1 T_2}{(T_2 - T_1)T_1}$$

$$= \phi J_{\Sigma_1} - \Delta\phi J\left(\frac{T_2}{T_2 - T_1}\right) = \phi J_{\Sigma_1} - \Delta\phi J\left(\frac{1}{1 - T_1/T_2}\right) \qquad (13)$$

and

$$I+N = \frac{\Delta\phi J \cdot T_1 T_2}{2(T_2 - T_1)} = \frac{\Delta\phi J}{2\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} = \frac{\Delta\phi J}{2}\left(\frac{T_1}{1 - T_1/T_2}\right) \qquad (14)$$

While, for the sake of the above example, a peak-to-peak measurement of jitter was used, it is clear that a similar development should be made for other measures such as root-mean-square (RMS). Commonly accepted measures of jitter heretofore have used peak-to-peak measure and it happens to have the simplest algebraic form for the present purposes. Nonetheless, other measures, particularly the RMS measure have certain merit.

The measurement technique of the invention, therefore, distinguishes between true jitter and the contribution of interference and noise to indicated jitter and by using appropriate equipment, signals can be obtained which represent true jitter and the interference and noise contribution to a detected jitter signal.

A representative arrangement for detecting true phase jitter is illustrated in the schematic block diagram of Fig. 3. In that arrangement, a test signal generator 10 supplies a sinusoidal test signal of, for example, 1000 Hz to a low frequency amplitude modulator 11 which modulates the amplitude of the test signal in accordance with a low frequency signal received

from a low frequency signal generator 12. Preferably, the signal provided by the low frequency signal generator is in the range of a few Hz, preferably about 1 to 5 Hz, and the modulation of the test signal by the amplitude modulator 11 in accordance with the low frequency signal should be in the range from about ten per cent to about fifty per cent since modulation levels above about fifty per cent may produce amplitude minima that may cause drop-out problems while at modulation below about ten per cent, the low signal-to-noise ratio in the output could be a matter of concern.

The amplitude modulated test signal from the modulator 11 is applied to a transmission system 13 to be tested and the output from the transmission system is supplied to a conventional peak-to-peak jitter detector 14 which generates an output signal representing the instantaneous peak-to-peak phase jitter in the received test signal. The peak-to-peak jitter detector 14 may be designed, for example, in accordance with the arrangement disclosed in the U.S. patent no: 3,711,773.

In order to sample the phase jitter signal at high and low test signal amplitudes, a test signal amplitude level selector 15 receives the transmitted test signal from the transmission system 13 and provides gate control output signals at outputs 16 and 17 when the test signal amplitude reaches selected low and high levels, respectively and supplies them to a low level gate 18 and a high level gate 19, respectively. The amplitude selector 15 also provides output signals representing the selected low amplitude level T_1 at an output 20 and a selected high level amplitude T_2 at an output 21. Those signals are, in turn, carried to a test signal amplitude ratio circuit 22 which produces an output signal representative of the ratio T_1/T_2.

A difference and ratio unit 23 is designed in a conventional manner to process the signal T_1, received from the output 20 and the signal T_1/T_2, received from the ratio circuit 22 to provide an output signal corresponding to

$$\frac{T_1}{2(1 - T_1/T_2)}$$

and another difference and ratio unit 24 is arranged with conventional circuitry to receive the signal representing T_1/T_2 from the ratio circuit 22 and provide an output signal representing the quantity

$$\frac{1}{1 - T_1/T_2}.$$

In addition, the output signals from the gates 18 and 19, representing the indicated phase jitter at high and low amplitude levels of the test signal, are supplied to a difference circuit 25 which produces a signal $\Delta\phi J$ corresponding to the difference between the high and low test signal amplitude phase jitter signals. That signal is, in turn, supplied to two product circuits 26 and 27 which also receive the outputs from the difference and ratio units 23 and 24 respectively, and are designed in a conventional manner to provide an output signal representing the product of the input signals. A difference circuit 28 receives the output from the product circuit 27 and subtracts it from the signal representing the low test signal level phase jitter received from the gate 18. The resulting signal from the circuit 28 corresponds to the true phase jitter, represented by the symbol K in expression (13), while the output signal from the product circuit 26 represents the noise and interference contribution N + I, to the detected phase jitter signal.

If desired, a visual representation of the variation in the detected phase jitter signal with test signal amplitude may be obtained by supplying the output from the peak-to-peak jitter detector 14 to the vertical deflection input terminal of an oscilloscope 29, and the output signal from the low frequency signal generator 12 to the horizontal deflection input terminal of the oscilloscope. The resulting oscilloscope image, corresponding to the graphical representation of Fig. 2, may be used to observe the variation in jitter as a function of signal amplitude.

Although the invention has been described herein with reference to a specific embodiment, many modifications and variations therein are possible. For example, the true amplitude jitter imparted to a test signal by a transmission system may be determined from a detected amplitude jitter signal by making appropriate modifications to the system illustrated schematically in Fig. 3. In addition, instead of utilising an amplitude measurement and computation system, it is equally possible to use other measurement and computation techniques, using, for example, a microprocessor or the like.

CLAIMS

1. A method for determining jitter components of a test signal received from a transmission

system comprising generating a sinusoidal test signal of selected frequency within the normal frequency range of the transmission system, modulating the amplitude of the test signal at a low frequency below the normal frequency range of the transmission system, generating an indicated jitter signal corresponding to an instantaneous jitter characteristic in the test signal transmitted by the transmission system, sampling the indicated jitter signal at high and low amplitudes of the test signal, and using the sampled jitter signals and signals corresponding to the high and low test signal amplitudes to generate a signal representing a true jitter component resulting from transmission of the test signal through the transmission system.

2. A method according to claim 1 wherein the indicated jitter signal includes components resulting from noise and interference and including the step of using the sampled jitter signals and signals corresponding to the high and low test signal amplitudes to generate a signal representing the noise and interference components of the detected jitter signal.

3. A method according to claim 1 including the steps of generating an indicated phase jitter signal corresponding to the instantaneous phase jitter characteristic in the test signal transmitted by the transmission system, and using the sampled jitter signals to generate a signal representing the true phase jitter component resulting from transmission of the test signal through the transmission system.

4. A method according to claim 3 including the step of using the sampled jitter signals to generate a signal representing the interference and noise components of the indicated jitter signal.

5. Apparatus for determining jitter components of a test signal transmitted by a transmission system, comprising test signal generating means for generating a test signal having a frequency within the range of the transmission system which is amplitude modulated at a frequency below the frequency range of the transmission system, jitter detector means providing a signal representing an instantaneous jitter characteristic of the test signal transmitted by the transmission system, sampling means for sampling the indicated jitter signal at two different amplitudes of the test signal, and means responsive to the sampled indicated jitter signals and to signals representing the two different amplitudes of the test signal for providing an output signal representing a true jitter component in the transmitted test signal.

6. Apparatus according to claim 5 including means responsive to the two selected jitter signals and to the corresponding amplitudes of the test signal to provide an output signal representing noise and interference components of the indicated jitter signal.

7. Apparatus according to claim 5 or claim 6 including oscilloscope means responsive to the indicated jitter signal and to the amplitude modulation of the test signal to provide a visual representation of the variation in detected jitter signal with test signal amplitude.

8. Apparatus according to any one of claims 5 to 7, wherein the jitter detector means comprises phase jitter detector means providing a signal representing the instantaneous phase jitter of the transmitted test signal and the means responsive to the sampled indicated jitter signals and the test signal amplitudes provides an output signal representing the true phase jitter of the transmitted test signal.

9. Apparatus according to claim 8 including means responsive to the sampled indicated jitter signals and the test signal amplitudes to provide a signal representing the noise and the interference components of the indicated phase jitter signal.

10. Apparatus for determining jitter components of a test signal transmitted by a transmission system substantially as described and as illustrated with reference to the accompanying drawings.

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